

ASSESSING LOW-PROBABILITY, HIGH-IMPACT EVENTS

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Assessing Low-Probability, High-Impact Events

I. Introduction

The economic evaluation of transmission projects has progressed to the point where a single base (or reference) case is often not sufficientⁱ. In order to understand the impact of uncertainty on the expected value and distribution of economic benefits, multiple cases are developed and evaluated. The process for developing these alternative cases is not clear for all stakeholders and is still evolving. The purpose of this paper is to provide an understandable summary regarding the following topics:

- Purpose of sensitivity cases
- Recent CAISO case study
- Proposed general methodology

II. Purpose of Sensitivity Cases

The value of a transmission expansion is dependent on a number of uncertain variables. These variables may include load growth, fuel prices, hydro conditions, generation entry and location, market power, and others. Some of these uncertainties can be easily quantified, and others cannot.

There are several fundamental reasons why uncertainty needs to be considered with respect to the transmission expansion benefits. The two primary reasons are:

- Expected Value
- Distribution of Benefits

Expected Value -- The uncertainty of future conditions may have a considerable impact on the value of the transmission line (i.e. higher-than-expected gas prices might increase the value of the transmission line significantly). The impact of this uncertainty on the expected value of the benefits may not be predictable without analyzing the base, high, and low cases specifically.

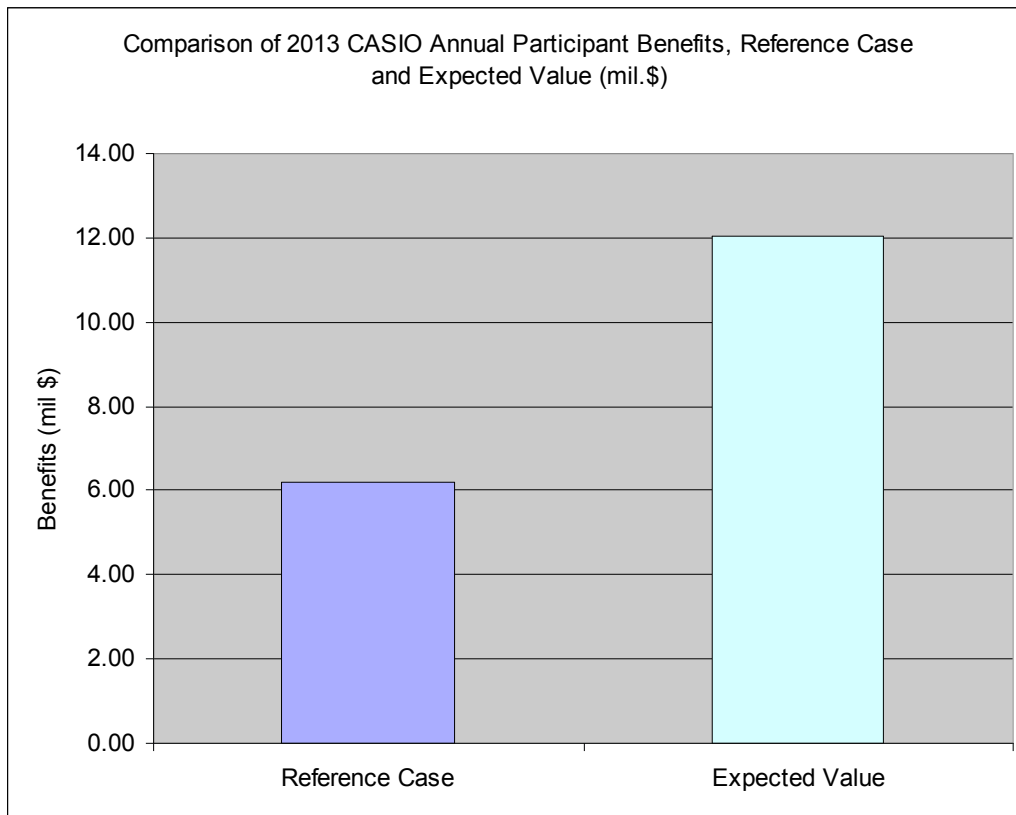
For example, the value of a proposed transmission addition assuming average future conditions may be \$40 million. Under a low-gas price case, the benefit might be \$30 million. And under a high-gas price case, the benefits may be \$60 million. The value of the transmission line under average conditions would be \$40 million. But the expected value of the proposed addition would be approximately \$43 million (assuming each of the three cases had an equal probability of occurrence). As illustrated in this simplified example, the reference case benefits (e.g. based on average conditions) can be significantly different from the “expected value” of benefits (e.g. derived from multiple sensitivity cases multiplied by their respective probability of occurrence).

ⁱ In this paper, the term “base case” and “reference case” are used synonymously.

Evaluating a transmission project based on average future conditions might underestimate, or overestimate, the true value of the expansion. Therefore, it is important to derive an “expected value” of benefits based on multiple cases, rather than just use the “average” benefits.ⁱⁱ

The difference between the average and the expected value of benefits may be insignificant or it may be considerable. In the Path 26 study developed by the California Independent System Operator (CAISO), the difference in annual benefits in 2013 from the CAISO Participant perspective was significant as is illustrated in Figure 1 below:ⁱⁱⁱ

Figure 1
Comparison of 2013 CAISO Annual Participant Benefits,
Reference Case and Expected Value (mil. \$)



The transmission benefits derived from a single reference or base case, compared to the expected value of benefits computed from numerous sensitivity studies, can be substantially different as shown in the example in Figure 2 above. Hence, it is important to calculate and use the “expected value” of benefits when comparing resource alternatives.

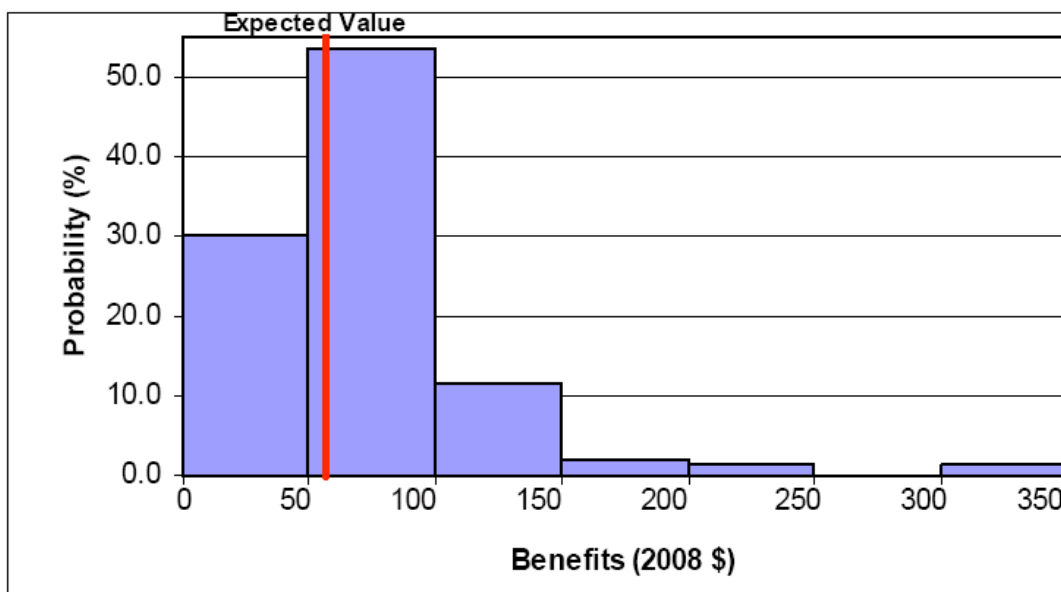
ⁱⁱ Average benefits are sufficient if the reference case is overwhelmingly economic or uneconomic. If the average benefits are not clearly economic or uneconomic, sensitivity cases are required to more accurately understand the expected value and distribution of benefits.

ⁱⁱⁱ “Supplement to the Transmission Economic Assessment Methodology Report” California Independent System Operator, (CAISO TEAM Supplement), July 28, 2004, pp. 5-3 and 5-5.

The comparison between the reference case and the expected value of benefits is generally not as significant as the difference shown in Figure 1. The two values can be much closer, or the order can be reversed with the reference case exceeding the expected value. All of these situations occurred in the CAISO Path 26 study (i.e. for different years and perspectives).

Distribution of Benefits – As discussed in the previous section, the expected benefit of the proposed transmission addition is derived from multiple sensitivity cases and their respective probabilities. This same information can be used to summarize the distribution of benefits. A distribution of benefits is a valuable decision-making tool in that the distribution summarizes the downside risks and upside-benefit potential of a resource alternative. An example of a probability benefit distribution for the proposed Palo Verde-Devers 2 (PVD2) expansion is shown in Figure 2 below

Figure 2
Probability Distribution of Energy Benefits,
2013, CAISO Ratepayer Perspective



The probability distribution of benefits above provides a snapshot of the relative risk associated with a given resource option or portfolio for a single year. This distribution allows the risk of a given investment to be quantified and used in the resource selection process.

In Figure 2, the blue vertical columns represent the probability that the energy benefits of the proposed PVD2 upgrade fall into the specified benefit range or bin. For example, there is a 30 percent probability that the annual energy benefits are between \$0 and \$50 million^{iv}. The red vertical line represents the expected value of benefits in the year 2013 from the CAISO Ratepayer perspective, which is \$56 million.

^{iv} The benefits of the proposed PVD2 are considered to include energy, operational, loss, capacity, and emission benefits. The “energy” benefits shown in Figure 2 are considered only part of the overall benefits. See CAISO PVD2 Report, p. 31.

Assume for the purposes of this example only, that the annual capital and fixed operating costs of the proposed upgrade are \$50 million. If the expected value of benefits is \$56 million, the benefits outweigh the costs and the project appears to be economically justifiable (for that year and perspective). Although this conclusion is valid, the distribution of benefits provides much more information, such as:

- There is a 70 percent probability that the annual benefits will be equal to, or greater than the annual costs.
- There is zero probability that the project will have non-positive benefits over a year (i.e. that the project will actually increase system costs).
- There is a 5 percent probability that the project will provide annual benefits of between \$150 and \$350 million, thus providing some insurance value against selected extreme events.

If another alternative had the same expected value of \$56 million, but the distribution showed limited upside potential and the possibility of negative benefits, on the basis of their risk distributions alone, the first alternative might be selected. Therefore, the benefit distribution is important for helping the decision maker(s) better understand the risks of a given alternative (i.e. probabilities to the left of the expected value) and the upside benefit potential (i.e. probabilities to the right of the expected value) relative to another resource alternative.

The probability distribution will also help indicate whether extreme events can be expected to have a significant impact on the expected value, and to what extent these cases should be developed and modeled. As a general observation, the expected value of transmission upgrades is expected to be significantly impacted by these extreme events (e.g. to the extent that the extreme events are able to be modeled and a probability assigned to them).

Dr. Frank Wolak, chairman of the CA ISO Market Surveillance Committee and a professor of economics at Stanford University, states that “transmission upgrades are particularly valuable during extreme conditions”. As an example, Dr. Wolak suggests that if a significant inter-connection existed between eastern United States and the WECC, prices in the WECC would not have risen to the levels that existed during the period of May 2000 to June 2001. Dr. Wolak has estimated that the savings that such an interconnect would provide during this time period would be “on the order of \$30 billion”.^v

Therefore, the inclusion of extreme events can be critical with respect to the derivation of both the expected value and the distribution of benefits.

^v “Valuing Transmission Investment in a Wholesale Market Regime”, Dr. Frank Wolak, Department of Economics, Stanford University, Chairman, Market Surveillance Committee, February 3, 2004, p. 13/29 (see website: <http://www2.caiso.com/docs/2003/03/18/2003031815303519270.html>).

III. Case Study -- Selection of Sensitivity Cases for PVD2

As discussed in the previous section, the inclusion of low-probability, high impact events (also referred to as “extreme events” in this report) generally has a significant impact on both the expected value and the probability distribution of benefits. The purpose of this section of the report is to provide a case study for the non-technical reader illustrating the methodology used to select and evaluate the low-probability, high-impact events.

The CAISO recently completed an evaluation of the economic viability of the proposed 1200 MW Palo Verde-Devers (PVD2) Project. This study analyzed the impact of uncertainty by developing numerous alternative cases. In theory, hundreds or thousands of cases could be developed for each transmission line, in order to evaluate the universe of possible future conditions and accurately derive the expected value and benefit distribution from a statistical perspective. Ultimately the selected sensitivity cases were developed through a stakeholder working group to identify both key concerns and high risk scenarios of potential interest to decision-makers.

In the PVD2 study, the four key variables that were expected to have a significant impact on the economic benefits are:

- Load growth throughout WECC
- Hydro conditions
- Natural gas price
- Generator market power

For each of these four key variables, three different cases are developed that generally correspond with very low, average, and very high conditions, based on a 90 percent confidence interval.^{vi} The possible combinations of these four variables are 81 sensitivity cases (3 x 3 x 3 x 3). Given the complexity of modeling each case for 8760 hours, two separate years (2008 and 2013), and using a detailed WECC transmission network, it is not possible to model each of the 81 cases separately.^{vii}

The CA ISO used a scientific sampling method called “Importance Sampling” to select a smaller, but still representative, number of all possible cases. Importance sampling is used to choose scenarios that represent:

- Most-likely conditions
- Extreme “bookend” conditions
- In-between conditions which are useful for analytic comparison

^{vi} CAISO Board Report, p. 8.

^{vii} The WECC representation used in the PVD2 study included 17,500 transmission lines, 13,400 nodes, 800 generation plants, etc.

For example, Dr. Benjamin Hobbs, a member of the CAISO Market Surveillance Committee (MSC) and a professor at John Hopkins University, used the following table to illustrate how we choose joint events of load and gas price levels using importance sampling. In this example, the most likely case is (B, B). The bookend cases are (VH, VH), (VH, VL), (VL, VL), (VL, VH). And the most useful analytic comparisons are (B, VH), (B, VL), (VH, B), and (VL, B). In Dr. Hobbs' example, after applying importance sampling, there are nine cases based on three levels for each variable, instead of the original 25 cases.^{viii}

Table 1
Application of Importance Sampling

		Demand Scenario				
		Very High	High	Base	Low	Very Low
Gas Price Scenario	Very High	X		X		X
	High					
	Base	X		X		X
	Low					
	Very Low	X		X		X

Extreme

Useful Analytic Comparison

Most likely

In the PVD2 study, Importance Sampling is used to subjectively select 25 sensitivity cases from the 81 potential cases. The 25 selected cases were designed to meet the three criteria summarized above: (a) most-likely; (b) extreme bookend; and, (c) those useful for analytic comparison.

After the number of potential cases is reduced significantly, probabilities were assigned to each of the 25 cases using a mathematical approach referred to as "Maximum Log-Likelihood"^{ix}. Of the 25 cases that were assigned probabilities with the Maximum Log-Likelihood, approximately 8 of those cases ended up with probabilities of zero. Thus, these 8 cases were dropped, and the remaining 17 cases were modeled. These 17 cases and their relative joint probabilities are summarized in the table below.^x

^{viii} "CAISO Proposed Transmission Expansion Evaluation Methodology – Sensitivity and Risk Analyses: Why and How", Benjamin Hobbs, CAISO Market Surveillance Committee, February 3, 2004 (see website: <http://www1.caiso.com/docs/2003/03/18/2003031815303519270.html>).

^{ix} "Economic Evaluation of Palo Verde Devers Line No. 2 (PVD2), Technical and Other Appendices", California Independent System Operator, (CAISO PVD2 Technical Appendices), Appendix A, p. 6 of 68.

^x For an introductory discussion of the Maximum Log-Likelihood algorithm, refer to website: http://statgen.iop.kcl.ac.uk/bgim/mle/sslike_4.html, section 3 (Maximum Log-Likelihood Primer).

Table 2
2008 Market-Based Cases with a Joint Probability

PVD2 Case Summary

A	B	C	D	E	F
Case no.	Load	Gas Price	Hydro	Market Pricing	Joint Probability
17	B	B	B	M	11.0%
18	B	B	B	H	5.0%
19	B	B	D	M	9.9%
20	B	B	W	M	13.1%
21	B	H	B	M	2.3%
22	B	H	B	H	1.8%
23	H	B	B	H	3.3%
24	H	H	D	M	1.8%
25	B	H	D	H	1.8%
26	B	B	B	L	15.0%
27	L	B	B	M	12.7%
28	B	L	B	M	10.1%
29	H	H	B	H	1.6%
30	H	L	B	M	4.9%
31	L	H	B	M	2.3%
32	H	H	D	H	1.5%
33	H	H	W	M	1.9%
High	15.0%	15.0%	15.0%	15.0%	
Base	70.0%	70.0%	70.0%	70.0%	
Low	15.0%	15.0%	15.0%	15.0%	
Total	100.0%	100.0%	100.0%	100.0%	100.0%

B = Baseline; H = High; L = Low; D = Dry; W = Wet; M = Moderate

One of the frequent questions that arose from stakeholders is if the low-probability, high-impact events are over-represented. For example, in Column C, there are eight cases of “high” gas prices and two cases of “low” gas prices (see Column D). It may appear to some stakeholders that the high gas case is over-represented.

However, if one adds the probabilities of all high gas cases, and then compares it to the probabilities of all “low” gas prices, the two probabilities both equal 15 percent. This is the same situation for each of the four variables. The probability of the high and low cases is 15 percent respectively, and the probability of the base case is 70 percent.

Developing additional “low” cases may not be particularly interesting since they represent cases that are primarily in the lower benefit ranges. For example, more “low hydro” cases would probably result in benefits for the proposed transmission expansion that range from \$0 to \$50 million. Additional low hydro cases would better define the shape of the benefit distribution curve below \$50 million, but these results are unlikely to change any decision to proceed or not with the development of the transmission expansion. On the other hand, understanding the low-

probability, high impact (or benefit) cases is important because of their potential impact on the expected value and understanding the upside benefits under extreme conditions.

A second question that was also frequently asked by stakeholders is why the joint probability of any individual case is not equal to the product of the marginal probabilities. For example, Case #32 in Table 2 is composed of four high events (high load, gas price, and market price, and dry hydro). The joint probability of those four outcomes is about 0.05 percent, almost zero, if one uses the marginal probability of 15 percent (i.e. $15\% \times 15\% \times 15\% \times 15\%$). Yet the probability shown in Table 2 is 1.5 percent, much higher than the calculated joint probability of 0.05 percent.

If we were to model the full universe of potential cases (i.e. 81 cases), then the joint probability for each case would be the product of the marginal probabilities for each of the four variables. However, since only 25 cases were selected through importance sampling for modeling, the probabilities of those cases must sum to one and represent the universe of cases. The mathematical approach used to assign probabilities to the 25 cases is called the Maximum Log-Likelihood linear program.^{xi} This technique is discussed further in the following section..

There are three types of sensitivity cases that the CAISO used in their evaluation of PVD2. These categories are:

- Cost-based cases
- Market-based cases with probabilities
- Contingency cases

The cost-based cases are used to understand the fundamental reasons for the benefits of the proposed transmission expansion without the additional complexity of trying to model market prices. These cases help identify modeling issues that need to be resolved before the market-based cases are developed. The cost-based cases are not used in the expected value or distribution of benefits calculations.

The 17 market-based cases summarized in Table 2 represent all information used to determine the expected value and and benefit distribution. The majority of the CAISO analytical effort was spent in developing these cases which are the backbone of the economic analysis.

The third category of cases is extreme events that cannot be assigned a probability. These cases are important from the perspective of understanding the value of the transmission line and the range of potential benefits, but since the contingency cases do not have a probability of occurrence, they are not included in the expected value or benefit distribution calculations.

In addition to the 17 market-based cases with joint probabilities summarized in Table 2, 8 contingency cases were developed to represent extreme cases that are difficult to assign probability to. The cases were picked by looking at major changes to generation or transmission which would affect the value of a new transmission line between Arizona and southern California. These contingency cases included:

- Year-long unavailability of key generation or transmission facilities including Palo Verde 1 and 2, Mountain View, San Onofre, and Pacific DC Intertie.
- Increased capacity made available by the inclusion of Mohave Generating Station in Arizona.
- 10 percent de-rating of the bulk transmission lines going north and southwest (California-Oregon Intertie and East-of-River interface)
- SCE early retirement of about 1000 MW of gas-fired, in-basin units^{xii}

^{xi} "CAISO PVD2 Technical Appendices", Appendix A, p. 6/68.

^{xii} "CAISO PVD2 Technical Appendices", Appendix A, p. 7/68.

IV. Proposed General Methodology

Stakeholders and decision-makers need a basis for evaluating whether a transmission benefit study has been constructed in a useful manner. In this section, a general framework for conducting benefits assessments is proposed. This framework is designed to be sufficiently basic that it can be readily used by resource or transmission planning departments in utilities, regulatory bodies, and market operators, as well as project proponents and interested interveners.

For the most part, the evaluation of a proposed transmission addition will include properly-selected sensitivity cases. However, it is important to recognize that in some cases, sensitivity cases may not be necessary. For example, if the computed Present-Value (PV) of benefits of the transmission expansion is significantly greater than the corresponding PV of revenue requirements, then further evaluation may not be critical if the additional analyses will not change the proposed decision. In a similar manner, if the PV of benefits is considerably less than the PV of revenue requirements, additional sensitivity cases may not be necessary.

For most transmission evaluations, however, sensitivity cases are important. The proposed general methodology for the selection and development of low-probability, high-impact cases consists of the following tasks:

- A. Establish stakeholder process
- B. Develop reference case
- C. Select uncertain variables
- D. Develop variable distributions
- E. Select sensitivity cases
- F. Determine joint probability
- G. Perform simulations and summarize results

A. Establish Stakeholder Process -- A properly designed and executed stakeholder process can be invaluable with respect to the proposed transmission addition and ensuring the project is reviewed in a comprehensive manner and reflecting alternative perspectives and priorities. An effective and efficient stakeholder process should result in an up-front agreement regarding which types of sensitivity cases should be included in the evaluation. To accomplish this, stakeholders must think about the purposes of the line, the kinds of uncertainties which might affect the value of the line, and the uncertainties which are of most concern to them. Only a subset of potential alternatives can be studied, so it is vital that parties agree on which studies are of most value. Otherwise, the proceeding may be delayed at a later point by concerns that the appropriate set of cases was not studied.

B. Develop Reference Case -- Before the uncertain variables are selected, it is important to develop a reference case which uses the base assumptions for all parameters. From this simulation and preliminary one-parameter sensitivity experiments, one can derive initial conclusions about the following critical information:

- The time required to correctly model each case including assumption development, execution, review, and iteration as appropriate.
- Those variables where their uncertainty have a significant impact on the results.

C. Select Uncertain Variables – In this task, variables that have a high degree of uncertainty, and a significant impact on the results are identified. These variables fall into one of the following three classes:

- Quantifiable event and known probabilities (e.g. hydro, load, fuel price)
- Quantifiable event and unknown probabilities (e.g. contingency studies)
- Difficult to quantify with unknown probabilities (e.g. new market paradigm)

The sensitivity studies will include the first two three classes of variables. However, only those variables that are quantifiable with known probabilities will be used in the expected value and distribution of benefits calculations.

D. Develop Variable Distributions - Once the uncertain variables are selected and their values for the base-case forecast, the next step is to develop a probability distribution. This distribution represents a plausible range of future values and their relative probability of occurrence.

There are several well-documented and accepted approaches for developing probability distributions including historical observations and forecast error. Since transmission evaluation depends on extreme events, a reasonable approach is to compile a base case and a range bounded by a relatively large confidence interval (e.g., a 90 percent confidence interval). The base case is the expected (or forecasted) value of the variable discussed in Task A. The following three levels can be considered for each uncertain variable:

Very High	upper bound of the 90% confidence interval
Base	expected value of the variable
Very Low	lower bound of the 90% confidence interval

Additional variable levels such as high and low are not included since their results are likely to be less informative or valuable than the extreme cases.

E. Select Sensitivity Cases – Using the concept of Importance Sampling, one can reduce the number of simulations required to a manageable level. If one has selected four variables that are quantifiable with known probabilities, the total universe of cases is 81. Using the three categories of cases outlined previously, the number of cases can be reduced to the following:

- Most likely – 1
- Bookend – 2 to 16
- Most useful for analytical comparisons – 8

The most likely case would be the base-case assumptions for all four variables. The bookend cases could simply be the very-high or very-low values for all four variables. The total combinations of bookend cases is 16 cases (i.e. 2^4). The analytical comparison cases would be one variable at either its very-high or very-low value with the other three variables set at a base or reference level. These cases are enumerated in Attachment A.

F. Determine Joint Probability – In order to ensure that all of the joint probabilities sum to one, and that the total probability of each variable sums to one (e.g. all low hydro cases should sum to 15 percent, base equal to 70 percent, and high equal to 15 percent), the use of mathematical approach such as the Maximum Log-Likelihood linear program is recommended.^{xiii}

G. Perform Simulation and Summarize Results – In this task, the actual market simulations are developed. Each case is modeled twice – “without” and “with” the proposed transmission addition. Generally, the societal results are reviewed first to ensure that the direction of the benefits (increase or decrease) are either intuitive or can be explained. Once the simulations are completed, a post-processing computation is used to determine the benefits from the desired perspectives such as California ratepayers, etc. Then the expected value and benefit distribution can be derived for the desired perspectives. Benefits can be interpolated for interim years, or extrapolated for remaining years using the expertise and judgment of the analyst.

^{xiii} In statistics, the likelihood is defined as the probability of specific input parameter given the observed results. For example, assume a coin is tossed 100 times and we observe 56 heads and 44 tails. Given those observed results, we can derive the maximum likelihood estimate (MLE) is a probability of 56 percent for heads. In a similar way, we are deriving the maximum probability of input parameters such as hydro. The reason for using the natural log of the likelihoods instead of the likelihoods themselves is computational rather than theoretical. With log-likelihoods, probabilities are simply added together instead of multiplied to reduce rounding errors and improve accuracy (Maximum Log-Likelihood Primer).

Attachment A
Possible Cases After Using Importance Sampling

Importance Sampling Criteria	Case No.	Case Descriptions
Most Likely	1	B,B,B,B
Bookend	2	H,H,H,H
	3	H,H,H,L
	4	H,H,L,H
	5	H,H,L,L
	6	H,L,H,H
	7	H,L,L,H
	8	H,L,L,H
	9	H,L,L,L
	10	L,H,H,H
	11	L,H,H,L
	12	L,H,L,H
	13	L,H,L,L
	14	L,L,H,H
	15	L,L,L,H
	16	L,L,L,H
	17	L,L,L,L
Most Useful	18	H,B,B,B
	19	L,B,B,B
	20	B,H,B,B
	21	B,L,B,B
	22	B,B,H,B
	23	B,B,L,B
	24	B,B,B,H
	25	B,B,B,L